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6. AUTHOR(S)
Drs. Charles A. Evans Jr. and Robert G. Wilson

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Charles Evans & Associates
810 Kifer Road, Sunnyvale, CA 94086

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13. ABSTRACT (Maximum 200 words)

Aims or goals of this work included growth, doping and characterization of new materials of interest to ARO for electro-optics and electronics aplication within the DoD, often involving support for university research through collaborative programs initiated by Dr. John Zavada.

A wide variety of materials were studied. The Group III-Nitrides were chosen as sources of multi-color LEDs and for high power/high temperature electronics. Rare earth elements were implanted into GaN to study their band edge luminescence and stimulated PL emission. Er, Pr and Eu implants into ZnO were also studied by these two optical techniques.

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TECHNICAL REPORT

Electro-Optics Based on Novel Materials Modifications

ARO Contract Number DAAD19-01-C-0042

Period covered: **1 Nov 2000** through **30 June 2001**

Performed at: **Charles Evans and Associates**

Principal Investigators: **Drs. C.A. Evans, Jr. and R.G. Wilson**

Introduction

This report describes work done and results obtained from 1 Nov 2000 through 30 June 2001. The report is divided into sections by technical area.

Aims or goals of this work included growth, doping, and characterization of new materials of interest to ARO for electro-optics and electronics applications within the DoD, often involving support for university research through collaborative programs initiated by Dr. John Zavada. A concomitant goal is the publication of papers that describe the results of this work and these collaborations.

The principal investigators for this program were Dr. C.A. Evans, Jr. of Charles Evans and Associates, and Dr. R.G. Wilson, Consultant.

Summary of work carried out, and results

III-Nitrides

Research related to the growth, characterization, and fabrication of devices in III-nitrides were a significant effort on this contract. III-nitrides are currently of great interest for both optical and electronic devices and applications, including blue, green, and violet LEDs and high power/high temperature electronics (microelectronics, especially microwave). Our contributions in this field included ion implantation for doping to create emitters in the near infrared (1-2 μm wavelength); and SIMS measurements of these dopants in the implanted

materials and in device structures grown in other laboratories, often under ARO contract support. The SIMS measurements provided both concentration and depth profiles.

Photoluminescence measurements are another important area of work in these nitrides. Band edge measurements are were made at Kansas State Univ. (Prof. X. Jiang) and longer wavelength measurements were made at Hampton University (Prof. U. Hoemmerich). Related papers are listed in the last section on Publications.

ZnO

We began a study of a new material, ZnO, for the applications mentioned in the Introduction. We implanted ZnO with Er, Pr, Eu, and Tm and sent samples to the two Universities mentioned earlier - for PL measurements of band edge and long wavelength radiation. We measured the depth distributions and atom densities of these implanted elements using SIMS; all were successfully implanted.

GaN, ZnO, and rare earth implantation

We implanted GaN and ZnO materials with Eu, Tm, Pr, and Er during this time period. We sent these samples to Kansas State and Hampton Universities for band edge luminescence and for stimulated PL emission measurements at 1.1, 1.3 or 1.5 μm wavelengths. One journal paper that resulted from the work carried out during this time period, was: C.J. Ellis, R.M. Mair, J. Li, J.Y. Lin, H.X. Jiang, J. M. Zavada, and R.G. Wilson, "Optical properties of Pr-implanted GaN and $Al_xGa_{x-1}N$ alloys," Materials Sci. Engr. **B81**, 167-170 (2001)

Ferro-magnetic Materials

A new thrust of this work was initiated at University of Florida by Prof. S.J. Pearton -- the creation of selective ferro-magnetic regions in wider bandgap materials. These regions can be created by the implantation of ferro-magnetic elements to various concentrations or percentages. The regions are necessarily near the surface, but any element can be introduced into any material to any concentration -- via the non thermal equilibrium process of ion implantation. Some processing probably must be carried out after implantation to optimize the ferro-magnetic effects. This is an area for study at Univ. FGlorida. Candidate elements for implantation include Cr, V, Mn, Fe, Co, Ni, and Gd. Candidate materials are many, but include SiC, GaN, and GaP.

We have been implanting these elements into materials supplied by Pearton. Papers are being prepared by the group at Univ. Florida, examples of which are listed below in the Publications section.

University Support

During the course of this contract work, we collaborated with research groups and university professors and their graduate students and post doctoral fellows. These collaborations are listed below.

Hampton University: Prof. U. Hoemmerich, J.T. Seo, M.Thaik, X. Wu
Kansas State University: Prof. H. X. Jiang, R.A. Mair, C.J. Ellis, J.Y. Lin
University of Cincinnati: Prof. A. Steckl
University Of Florida: Professors S.J. Pearton, C. Abernathy, and F. Ren, and M. Overberg, X.A. Cao, R.K. Singh, J.R. LaRoche, J.R. Lothian, J.W. Lee, C.-M. Lee, C.-C. Chuo, G.-C. Chi, G.T. Dang, A.P. Zhang, S.N.G. Chu, L. Zhang.

Meetings with ARO personnel

Because John Zavada was located in London during the time of this contract work, communication between Wilson and Zavada was carried out via email whenever appropriate (about once each month) and by fax or phone about once every two months.

Publications that resulted from this program

Technical details of work that was performed under this contract are described in the references listed below.

N. Theodoropoulou, K.P. Lee, M.E. Overberg, S.N.G. Chu, A.F. Hebard, C.R. Abernathy, S.J. Pearton, and R.G. Wilson, "Nanoscale magnetic regions formed in GaN implanted with Mn," J. Nanosci. and Nanotech. 1, 101-06 (2001)

S.J. Pearton, K.P. Lee, M.E. Overberg, C.R. Abernathy, N. Theodoropoulou, A.F. Hebard, R.G. Wilson, S.N.G. Chu, and J.M. Zavada, "Magnetism in SiC implanted with high doses of Fe and Mn," J. Electron. Materials. x, xxx-xx (2001)

K.P. Lee, S.J. Pearton, M.E. Overberg, C.R. Abernathy, R.G. Wilson, S.N.G. Chu, N. Theororopolou, A.F. Hebard, and J.M. Zavada, "Magnetic effects of direct ion implantation of Mn and Fe into p-GaN," J. Electron. Materials. **x**, xxx-xx (2001)

M.E. Overberg, N. Theodoropoulou, S.N.G. Chu, S.J. Pearton, C.R. Abernathy, A.F. Hebard, R.G. Wilson, and J.M. Zavada, "Effects of Ni implantation into bulk and epitaxial GaP," J. Electron. Materials. **x**, xxx-xx (2001)

S.J. Pearton, N. Theodoropoulou, M.E. Overberg, C.R. Abernathy, A.F. Hebard, S.N.G. Chu, R.G. Wilson, and J.M. Zavada, "Characterization of Ni-implanted GaN and SiC," J. Electron. Materials. **x**, xxx-xx (2001)

C.J. Ellis, R.M. Mair, J. Li, J.Y. Lin, H.X. Jiang, J. M. Zavada, and R.G. Wilson, "Optical properties of Pr-implanted GaN and $Al_xGa_{x-1}N$ alloys," Materials Sci. Engr. **B81**, 167-170 (2001)

S.J. Pearton, K.P. Lee, M.E. Overberg, C.R. Abernathy, N. Theodoropoulou, A.F. Hebard, R.G. Wilson, S.N.G. Chu, and J.M. Zavada, "Magnetism of SiC implanted with high doses of Fe and Mn," J. Electron. Materials. **x**, xxx-xx (2001)